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THE INJECTION OF CHEMICALS INTO CHESTNUT TREES[1]

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The rapid spread of the chestnut bark disease caused by *Endothia parasitica* (Murr.) A. and A. in the eastern part of the United States during the past ten years and the resultant appeals for help from owners of ornamental chestnut trees and of chestnut orchards, reluctant to lose their trees, were the reasons for this experimentation.

As a rule the fungous diseases of plants are such that the application of sprays, crop rotation, fertilizers, and sanitary methods of cultivation prevent or hold them in check. This disease, however, like many others to which trees especially are subject, can not be treated in this way. The cause of the sickness is in a part which can not be reached by any outside application of medicine, fertilization of the soil will not help, nor will sanitation prevent, at least in many parts of the eastern states.

The customary method of keeping such a disease in check has been to cut away and burn the diseased parts or the entire trees. The money value of the individual trees caused discontent with this method.

Experiments on tree injection were undertaken as a possible remedy. It was believed that from its nature this treatment could not be applied to forest trees. Only such trees as had a definite commercial or aesthetic individual value would repay the requisite cost and trouble.

HISTORY OF PLANT INJECTIONS

The idea of introducing foreign substances into plants is two centuries old. In 1709 Magnol (cited by Sachs, 1) introduced colored solutions into plants in order to find through what channels the sap passed. These first injections were made by placing the cut stems of leaves, twigs, or flowers in the solutions. McNab (2) was the first to put lithium into trees. He used caesium as well. About this time Pfitzer (3) injected salts of thal-

[1] The Pennsylvania Chestnut Tree Blight Commission was responsible for the starting of this experimental work in 1912; Investigations in Forest Pathology, Bureau of Plant Industry, for its continuation in 1913–1914 and in part for its continuation until 1918. The University of Pennsylvania furnished laboratory facilities, greenhouse, and many supplies. To Mr. Harold Peirce of Philadelphia, Secretary of the Commission, belongs the credit that these experiments were continued to their present stage.

lium. In 1887, Gaunersdorfer (4) published the results of seven years of experimentation on the effect of lithium sulphate on plants. He injected small conifers without injuring them and found that the plants finally eliminated the salt introduced into them through the roots by throwing it off with the leaves and bark. He believed young shoots, leaves, and reproductive organs were protected from the lithium by the lack of lignified water-transferring tissue. Physiologists such as Sachs (5), Strasburger (6), Wieler (7), and Pfeffer (8) established the fact that some substances foreign to plant tissues could be safely conducted through them. At the same time a large number of substances were found to be poisonous. In general, the response given by the plants to the poisons resembled that given by animals, *i.e.*, a very small amount of poison could be introduced into them without injury or noticeable change; a still larger amount increased their activities, often their growth; a larger amount retarded their activities, while still more killed. A plant could furthermore become accustomed to a poison to a certain limit, provided the poison was introduced into it in small quantities at first and these doses gradually were increased. Doses could in the end be administered without detriment that would otherwise have killed at once.

The idea of injecting trees for purposes of wood preservation is also old. In 1840 and 1841, Boucherie (9) published accounts of experiments in which chemicals were injected into living trees. His method of injection killed the tree. The introduced liquid was distributed up and down the trunk, the injected area decreasing rapidly in breadth toward the roots. Fall was the best season for a complete saturation by this method, but it could be done in the spring. Coniferous trees were an exception because sap movement took place in them throughout the winter. Different substances were absorbed at different rates; neutral salts penetrated the wood in large quantities, acids and alkalies to a less extent. If there were hard knots or rotten spots at the base of the tree, the whole strip of wood above them would not be saturated at all. The same was true of the old wood of hard wood plants. Boucherie's ideas were used by Shevyrev in his work.

The first paper on tree injection for purposes of medication was that by Ivan Shezyrez (J. Shevyrev, Schewirew or Chewyreuv) (10). The most of Shevyrev's experiments on the injection of living trees were made with stains for the purpose of establishing the fact that solutions of substances foreign to tree tissues could safely be introduced into trees. He mentions injecting grape vines with copper sulphate but does not give the results. He describes his methods of injection and his theories as to tree injection as follows:

The best time for injection is the late summer and fall. The liquid is distributed to all parts of the tree, with the exception of the dead portions. The liquid enters the roots as well as the leaves, twigs, and fruits. This current takes the place of the sap, ascending and descending, the only dif-

ference being that it is an unusual (extraradicate) instead of the usual (radicate) current. The duration of this created second sap movement does not exceed five days. The most intensive absorption takes place at the beginning, gradually diminishes, and ceases entirely in from three to five days. He believed this diminution and cessation due to the obstruction of the vessels. Shevyrev found that the weather greatly influenced the rate of intake; he made a record of the hourly intake of an injected grape vine and of the weather for a period of three days, which showed that the consumption at night was less in quantity than that in the day, regardless of the weather.

Shevyrev's experiments were made primarily for the purpose of destroying such insects as injure plants by burrowing beneath the bark. He believed, however, that fungous diseases could be cured by the same method.

Shevyrev did not continue his experiments. The last paper (11) he published on the subject describes and criticizes the injection experiments of some Russian workers who had been treating diseased trees. He speaks of the experiments of K. K. Reshkv or K. Reschko in the Crimea, to which no other reference could be found by the present writer. Reschko treated in 1901, according to Shevyrev, a thousand trees suffering from chlorosis by introducing iron sulphate into canals cut in the bases of the diseased trees. The distribution of the substance was found to be irregular, so that individual branches were found to be uninjected.

Pachassky (12), in a governmental report of 1903, reported favorably on the injection of iron sulphate either in powder or in solution in the treatment of diseased fruit trees.

C. A. Mokrjetsky (S. A. Mokrzecki or Mokrzhetski) (13), in governmental reports of 1902 and 1903, tells of injecting more than 500 trees, the method of injection being analogous to Shevyrev's. Diseased apple trees were cured with iron sulphate, gummosis of apple, pear, and other trees with 1 percent salicylic acid. He injected "nutrient solutions" into frost bitten trees, which recovered rapidly after treatment and grew three times as much as the untreated trees. Another article (14) "Uber die innere Therapie der Pflanzen" explains his work in more detail. The two methods of injection used are explained. One of them consists of inserting the dry salt in holes bored in the tree trunk. These holes are then closed with grafting wax. In the other method solutions are injected. The hole made in the trunk for the purpose of injecting is bored with a brace and bit which passes through a metal tube embedded in the tree. A side outlet in this tube is connected by a rubber tube with a jar containing the solution to be injected. As the hole is bored by the brace and bit the solution passes into it, thus shutting out the air from the wound. Diseased trees were injected with copper sulphate, calcium cyanide, and arsenic in 1/100 percent concentration, with inconclusive results. Iron sulphate in 0.05–0.25 percent solutions (amount injected not stated), or the dry salt, 12

grams for trees with 16–25 cm. diameter, cured apple trees of disease and insects. Mokrjetsky stated that he was carrying on more experiments as he believed that the fertilization of plants with such injected salts often cured them at the same time of diseases.

The best reports on tree injection so far printed are the Russian. Most of the experiments were made in the Crimea. Here many of the fruit trees appear to suffer from malnutrition, according to Mokrjetsky (14), and the iron sulphate appeared to act as a most efficient fertilizer. The dry, hot summer climate of this region favored the rapid consumption and transfer of the injected solutions, to which the trees reacted in a striking manner. No reports have been found as to the length of time the injected iron sulphate acts as a fertilizer, except a statement by Mokrjetsky that in the spring following the injection the buds on the fruit trees were numerous and large. The Russian experimenters appear to have stopped, unfortunately, before they had concluded their work. In 1912 the writer received a letter from Shevyrev saying that he was unable to continue the injections and hoped that the work would be carried on in this country.

A series of short papers by German, French, and American workers followed Shevyrev's publications.

Roth (15) in 1896 described a method and apparatus for injecting trees.

Mangin (16) in 1898 unfavorably criticized plant injection, especially the idea that grape vines could be protected from fungi by the injection of salts. He regarded plant injection impracticable in agriculture.

Goff (17) found the injection of water into the roots of newly transplanted trees to be beneficial. He described his apparatus and method of injection. His experiments showed that this treatment hastened the initial growth of the trees.

Bolley (18) in three reports described experiments in stimulating tree growth by injecting liquid solutions into the trunk. He successfully treated diseased apple and plum trees with a formaldehyde solution of 1/2 to 2 parts per 1000 of water. He reported that the effect of injected solutions on parasitic diseases was inconclusive.

Simon (19) reported that he successfully injected apple and peach trees, grape vines, and potatoes. Water solutions of purin and potassium nitrate and nutrient solutions were used. Copper sulphate injected into grape vines was at first injurious, but later the vines produced new leaves free from fungi.

Fron (20), using Simon's method of injection, treated pear trees with solutions of iron sulphate and calcium nitrate. The vigor of the trees appeared to be increased, but the improvement was confined to portions of the trees only. He believed this method of little practical value in fruit culture.

Coffigniez (21) experimented about the same time with iron sulphate and fruit trees in the control of fungus diseases.

Sanford (22) published a note on the effect of potassic cyanide on the scale. He considered the insertion of the salt beneficial to the tree. This result was disputed by Surface (23), Shattuck (24), Moore and Ruggles (25), and Flint (26). The experiments of the latter-named workers showed the injurious effects of a concentrated solution of cyanide of potassium on plant tissues. No attempt was made to try the effect of a gradual impregnation with dilute solutions of the salt. These articles are reviewed by Elliott (27) in a publication which describes the effect of cyanide of potassium on woody and herbaceous plants. Elliott worked with a killing solution, as he inserted the crystals under the bark and epidermis of the plants and depended on the sap to dissolve the crystals. The reactions of the plants were extreme, the tissues in the path of the solution being killed when the solution was concentrated. He found that the weather had a decided effect on the kind of reaction and the time of response of the tree. Trees treated on cool, damp days responded more slowly and showed less extensive injury than those treated on hot, dry days. He found also that the rate of transpiration affected to some extent the path of the solution. When transpiration was slow the solution passed into the cells surrounding the vessels; when it was rapid the solution appeared to pass through the vessels without going into the surrounding cells.

Rankin (28) injected ten chestnut trees with lithium nitrate solutions varying from 0.1 to 0.002 percent. His analysis of the trees showed that the salt had penetrated the bark and sapwood above and below the place of injection. When trees were less than three inches in diameter there was complete penetration of the heartwood, but in trees of greater diameter the penetration did not seem to follow a definite rule, the heartwood sometimes being impregnated, sometimes not. The tip of the trees was found impregnated. Aside from blotching of leaves the trees were not injured.

The Russian and American papers give the most definite reports, both as to practical methods of injecting and as to the results of the injection.

The Problem

In studying such a problem as the injection of a tree, a number of fundamental considerations present themselves:

A substance in solution injected into a tree generally passes through those vessels in the neighborhood of the place of injection through which the crude sap ascends from the roots to the leaves. It can also descend through those vessels, but in all of this there is lacking that persistent passing and returning of a stream such as constantly bathes the cells of the animal body.

The streams passing through this region, besides varying constantly in rate of flow, content, concentration, and acidity, are also under different atmospheric pressures.

The physical attributes of the cells must be considered. The surface of the cell walls, aside from the semipermeable membranes of the living cells in the region of the vessels, offer surface films which are constantly within the field of absorptive and adsorptive forces.

The chemical content of the sap may be changed by the injections, insoluble mineral compounds may be formed and toxins made harmless thereby.

These conditions at this stage of experimentation called for a great deal of empirical experimental work with chestnut trees.

In order to study this subject fundamentally, an attempt was made to answer by means of experimentation the following questions: (1) What substances can be injected into living chestnut trees? (2) When can they be injected? (3) Where does the injected material go? (4) What is the effect on the chestnut tree? (5) What is the effect on the fungus growing parasitically on the trees?

The present record gives the results of five years' experimental work. The work here reported is not complete. The propositions offered for solution have, however, been so varied in character that it seemed proper to bring together in this and a succeeding paper the different results so far secured, since this work must for the present be laid aside.

Experimental Procedure

Experimental Plots

The principal experimental plots of trees were in the center of a blight-infected chestnut orchard of some three hundred-odd acres' extent, located in southeastern Pennsylvania. They were on top of a hill about 500 feet above sea level. This region is hilly and originally was covered by a mixed forest of conifers and deciduous trees, a large proportion of the deciduous trees being chestnuts. The fact that this is the fourth generation of chestnut trees growing here since the Revolutionary War shows how favorable is this region to the growth of chestnut.[2]

Trees

The trees used in the experiments were orchard trees, for the most part Paragon scions grafted on native chestnut stock, *Castanea dentata*. The trees in the plots varied in age according to the year of grafting. One set was about ten, the other fourteen years old. They were short, stocky trees

[2] An analysis for alkali content was made of the soil by the Bureau of Soils, Department of Agriculture.

K_2O	trace	
CaO	0.27%	No CO_2 from carbonates.
MgO	0.68%	
P_2O_5	trace	
N	0.08%	
Li	none	

in form, the greatest height being about five meters, the mean height four meters. The orchard had never been pruned or cared for other than by cutting out the underbrush just before the chestnut harvest each fall.

In 1912, when the plots were chosen, they were cleared of underbrush and dead infected trees and were kept clear. Such cankers as threatened soon to girdle the trees were cut out under sanitary conditions. The remaining cankers on the trees were outlined with paint in order to note their rate of growth. The apparatus used in making the injections has been described elsewhere (29)[3].

Injections

Generally two injections were first made in a tree, on opposite sides of the trunk. The next two injections were at right angles to the first two, a little higher up the tree. If more injections followed they were made still higher up in the spaces between the first injections, or on the branches. Observations on the trees injected with substances which blotched the leaves showed that in this way all the branches on the tree could be reached. The hole cut for injection was one centimeter in diameter, and the width of two annual rings of wood into the tree's interior. All the records are based on the intake through holes of this size.

All the substances injected were dissolved in water. This water came from a spring in the orchard and was very lightly mineralized.[4]

[3] In 1915 a different method of injecting trees was tried. In place of the clamps used in the old method, link chains tightened by turnbuckles hold the perforated rubber corks against the tree trunk. The corks are protected from the metal chain by iron washers. Glass T-tubes thrust through the corks introduce the salt solution into the injection holes. The tubes leading from the reservoirs are attached to the vertical ends of the T-tubes. The free ends of the horizontal arms of the tubes are tipped by pieces of rubber tubing. A tempered steel tube shaped like a laboratory cork borer makes the holes in the trunk. It can be driven into the tree through the horizontal arm of the T-tube after the apparatus is in place and the solution fills the T-tube. The solution is cut off by a pinch cock placed over the end of the rubber tip after the drill has been removed. Glass T-tubes were found to be safest for this work because the presence of air bubbles, or leakage in the connections, could be detected easily. It is necessary, for a good injection by this method, that no air enter the injection hole. Seven injections at a time have been made by this method.

[4] Analysis of water by Bureau of Chemistry, Department of Agriculture:

	Mg. per liter
Silica (SiO_2)	5.8
Sulphuric acid (SO_4)	0.8
Bicarbonic acid (H_2CO_3)	10.4
Nitric acid (NO_3)	0.5
Chlorine (Cl)	1.5
Iron (Fe)	0.2
Aluminum (Al)	0.0
Calcium (Ca)	1.2
Magnesium (Mg)	0.9
Potassium (K)	0.7
Sodium (Na)	2.0

The water was tested for heavy metals, lead, copper, etc., none being found.

Measurement of Intake

The intake of an injected tree was measured by weighing the jars containing the solutions. This was done with a small brass beam-balance which recorded the weight in grams. It was assumed that a cubic centimeter of the solution weighed a gram. It was thought that the amount of error caused by this assumption was so small as not to need to be calculated when estimating the amount of substance injected into a tree. Experiment showed that the amount of evaporation from the jars through the parchment covering was so small that it could be ignored. This amount was found to average 40 cc. per month. If the paper cap was torn the average evaporation was 70 cc. per month.

There was also evaporation of the more volatile substances in dilute solution. This could be noticed in the case of the cresols and phenols and of some of the ammonium solutions. The amount of this loss was not tested. The jars containing such solutions had their contents renewed frequently, and an attempt was made by reinjecting to keep the solutions going into the trees rapidly. These precautions were thought to be sufficient to make it unnecessary to calculate either the loss or the concentration of substance due to such evaporation in the experimental work so far attempted.

Substances Injected

The following substances weıe injected into the trees:

Inorganic Substances	*Organic Substances*
Copper sulphate	Methyl alcohol
Copper chloride	Formalin
Zinc carbonate	Acetic acid
Mercuric chloride	Formic acid
Potassium chromate	Lactic acid
Potassium bichromate	Citric acid
Barium chloride	Aniline sulphate
Colloidal cuprous hydroxide[5]	Phenol
Colloidal metallic silver	Sodium carbolate
Colloidal metallic mercury	Phenol Sodique[6]
Potassium carbonate	Para nitro phenol
Potassium hydroxide	Ortho nitro phenol
Potassium sulphate	Picric acid
Ammonium carbonate	Meta cresol
Ammonium chloride	Para cresol
Ammonium hydroxide	Thymol
Ammonium sulphate	Pyrocatechin
Sodium carbonate	Pyrogallic acid

[5] I am indebted to H. K. Mulford Company of Philadelphia for these colloidal preparations. The metals were protected in each case by a second colloid.

[6] A patent medicine made of carbolic acid and caustic soda.

Sodium chloride
Sodium hydroxide
Lithium carbonate
Lithium chloride
Lithium sulphate
Lithium hydroxide
Lithium nitrate

Water

Phloroglucin
Oil of bitter almonds
Benzoic acid
Salicylic acid
Bark extracts
Water extract of chestnut tree bark
Water extract of chestnut blight canker

Stains:

Methyl green
Methylene blue
Eosin
Congo red
Trypan blue

All these substances went into the trees in measurable quantities.

Solutions

The solutions were made *gram molecular* except in the case of stains, the bark extracts, formalin, Phenol Sodique, and ammonium hydroxide.

For instance, if a solution of anhydrous sodium carbonate 1/200 G. M. is used, the molecular weight of sodium carbonate is found, which is 106.10. 106.10 grams of salt added to a liter of water makes a gram molecular solution, and a solution 1/200 G. M. means that 1 cc. of the G. M. solution is added to 199 cc. of water.

The chemicals used were bought as chemically pure.

But one substance was injected into a single tree. In a few cases, all of which are indicated in a following list, stronger solutions were used in the later than in the earlier injections in a tree.

Number of Trees Injected

Usually three or more trees were injected with the same substance. The exceptional cases in which fewer than three trees were injected are as follows: But one tree injected: methyl alcohol, Phenol Sodique, oil of bitter almonds, and para cresol. But two trees injected: zinc chloride, barium chloride, colloidal metallic silver, and colloidal metallic mercury. The largest number of trees injected with one salt was thirteen, injected with lithium carbonate solutions of different dilutions. Nineteen check trees were injected with water.

Some of these trees were injected two years in succession, some three years, the greatest number but one year.

The injections were made in 1912, 1913, and 1914. In 1913 a record of the weather was kept together with a record of the daily intake of the trees, so that all remarks on the rate of intake of the trees will be confined to the

records of this year. The records of the previous and succeeding years confirm the 1913 figures.

Rate of Absorption of Injected Substances

This compilation was made from the records of the injections made in 156 Paragon chestnut trees during the growing season of 1913 and of the weather during that period.

The therapeutic bias of the work decidedly limited the scope of the experimental injections, and in consequence data are wanting for a complete record of the rates of intake. The effort was to find the dilution at which a substance entered a tree readily without killing it. When a tree showed injurious effects of an injection, the injection stopped whether it had been going for two days or for a week.

It was the policy in 1913 to inject large quantities of dilute solutions, on the supposition that the dilution decreased the toxicity of the substance near the point of injection. At the same time the tendency of the lignified cell walls to retain the substance was relied on to dilute the solution still further in its passage toward the leaves, so that the latter would not accumulate so much before autumn as to cause them to die. In consequence of this effort the data on the rate of absorption are very incomplete.

Table I. *Substances, with Their Dilution, Injected Into Trees*

No. of trees	Substance	No. of trees	Substance
	Ammonium:		
4	$(NH)_2CO_3$ 1/100 G.M.	3	Acetic acid
4	$(NH_4)OH$ 1/100 approximately		(2) 1/1000 G.M.
6	$(NH^4)_2SO_4$		(1) 1/3000
	(1) 1/100, changed later to 1/50	3	Benzoic acid
	(2) 1/100		(1) 1/1000
	(2) 1/200		(2) 1/5000
	(1) 1/500	3	Citric acid
2	NH_4Cl 1/200		(1) 1/500
	Sodium:		(1) 1/3000
7	Na_2CO_3		(1) 1/5000
	(4) 1/100	3	Formic acid
	(2) 1/200		(1) 1/1000
	(1) 1/500		(2) 1/6000
4	NaCl	3	Lactic acid
	(3) 1/100, changed to 1/50		(2) 1/1000
	(1) 1/200, changed to 1/50		(1) 1/2000
7	NaOH 1/100 G.M.	4	Picric acid
	Lithium:		(1) 1/500 G.M.
5	LiOH		(1) 1/1000
	(1) 1/200		(2) 1/10000
	(3) 1/500	2	Pyrogallic acid
	(1) 1/1000		(1) 1/100
5	Li_2C		(1) 1/1000
	(1) 1/200	3	Salicylic acid

(1) 1/500, changed to 1/100
(1) 1/5000, changed to 1/1000
(1) 1/1000, changed to 1/500
(1) 1/100
4........LiCl
(2) 1/100
(2) 1/200
Potassium:
4........KOH
(2) 1/100
(2) 1/200
4........K_2CO_3 1/100
4........K_2SO_4 1/100
5........Colloidal copper
(5) 1/3300
2........Colloidal metallic silver
(2) 1/6400
2........Colloidal metallic mercury
(2) 1/6400
3........Potassium bichromate
(1) 1/1000
(2) 1/5000
5........Potassium chromate
(1) 1/5000
(1) 1/1000
(3) 1/1000
1........Copper sulphate
(1) 1/100
(2) 1/5000
(1) 1/10000
3........Aniline sulphate
(3) 1/1000
3........Meta cresol
(3) 1/1000
1........Para cresol
(1) 1/1000
4........Ortho nitro phenol
(2) 1/1000
(2) 1/100000
3........Para nitro phenol
(2) 1/500
(1) 1/1000
1........Oil of bitter almonds
(1) 1/1000
1........Phenol Sodique
(1) 1 cc. to 1,000 cc. H_2O
3........Phloroglucin
(3) 1/1000
3........Pyrocatechin
(1) 1/500
(2) 1/1000
3........Sodium carbolate
(3) 1/1000
3........Thymol
(1) 1/1000
(2) 1/3000
1........Methyl alcohol
(1) 1/100
2........Methylene blue
(2) 1 gm. to 4,000 cc. H_2O
2........Trypan blue
1 gm. to 4,000 cc.
Bark extracts:[7]
3........Healthy bark
(3) 1 cc. to 99 cc. H_2O
2........Canker extract
(2) 10 cc. to 990 H_2O
3........Canker extract-citric acid
(3) Canker ext. 1 cc. to 100 cc. H_2O, with citric acid 1/500 G.M.
13........Water checks

The records of absorption were divided into months for convenience in tabulating. It was found that injections could be made in February and March, when the rate of intake was very slow. The regular injections began in April, but the records for this month were not typical because it

[7] The bark extracts were made by soaking for 24 hours the shredded bark and young wood in spring water. The proportions were 10 cc. of water to 1 g. of healthy bark or of canker tissue. The extracts were filtered before using.

was not until the latter part of the month that injection and weather-recording apparatus were in running order.

The daily intake of the trees was measured each morning, and usually the injections were made in the morning. The hourly intake was not measured, but experience confirmed Shevyrev's observations that the intake by day was greater than by night.

The records of series of injections in individual trees showed that the number of the injection did not influence the amount of solution which went into the tree, *i.e.*, at the sixth injection more cubic centimeters might go into the tree than at the first, or the third injection in the month might be more successful than the first or second. As has been explained, (page 7), care was taken that the new injection was not made directly above or below the old injection hole.

The intake of the trees in the different months was computed and plotted on ruled paper in order that estimates of the rates could be made.

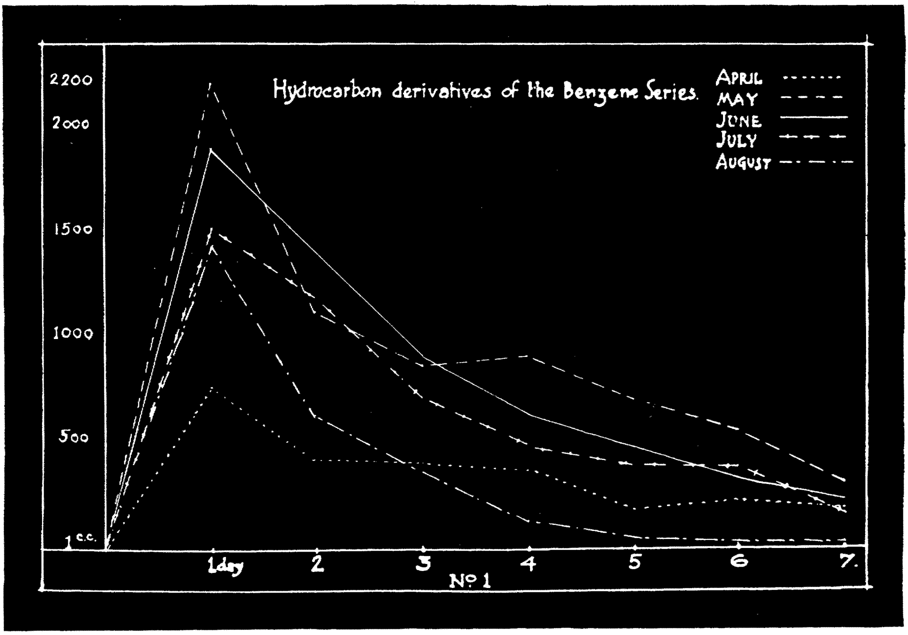

FIG. 1. Graph showing the rate of intake of trees injected with the hydrocarbon derivatives of the benzene series during the spring and summer months.

In computing, the *mean* of the intake of all the injections of a tree during the month represented the monthly intake of that tree per injection.

Plotted curves showing the rate of intake are more varied for April, May, and June than were those for the summer and autumn months. Figures 1, 2, and 3 show the *mean* intake a day per tree reckoned from the day of injection for seven days, of all the trees injected with alkali metals,

organic compounds, and water. As the number of trees being injected varied from month to month, these curves simply approximate the rate of intake.

93 trees are represented in the curves of the hydrocarbon derivatives of

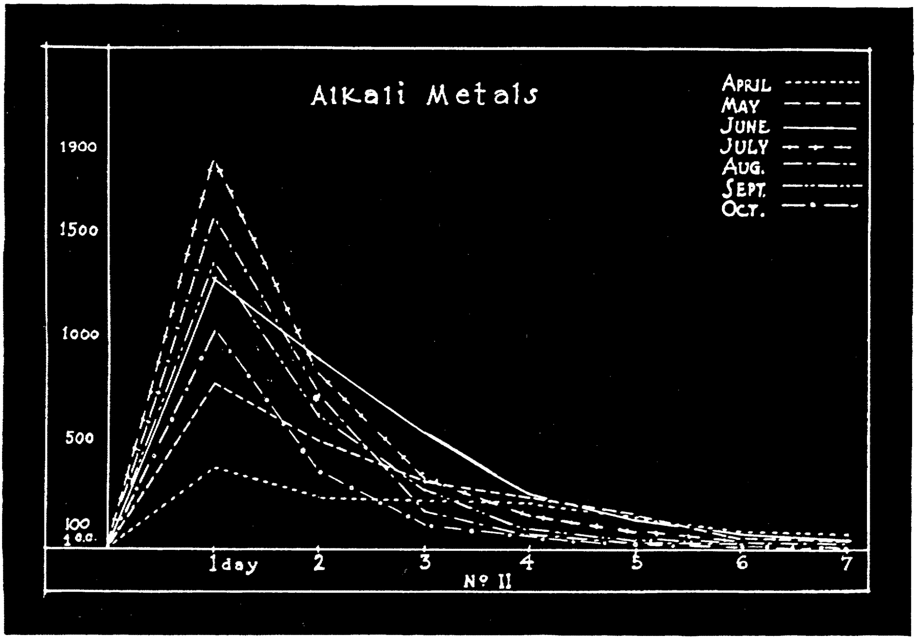

FIG. 2. Graph showing monthly rate of intake of trees injected with the alkali metals.

the benzene series: 7 trees in April, 17 trees in May, 26 trees in June, 33 trees in July, and 10 trees in August. The curve for May, for instance, represents more than 17 injections, for, as has been explained (p. 7), two injections were made in a tree on opposite sides of the trunk, and the daily amount of intake of an injected tree was the mean intake through two injection holes. In May it happened that many of the injections continued for two and three weeks. (The more readily the solution flowed into the tree the fewer were the reinjections.) A number of the trees were injected during one month only, very few for three months, so that no comparison between the intake of a solution by a single tree in the different months could be made. For these reasons the curves approximate the rate of intake, as has been previously stated.

The curves representing the alkali metals are better representations because more trees (121) are represented: 9 in April, 8 in May, 9 in June, 26 in July, 33 in August, 30 in September, and 17 in October. Not only are more trees represented, but more injections to a tree. In spite of the large number of trees, the curves for April, May and June are not typical,

being depressed by the ammonium solutions (counted with the alkali metals), which were injected at this time when comparatively few trees were being treated.

With hardly an exception the rate of intake for the solutions, irrespective of whether they were acid, neutral, or alkaline in reaction, was greater than for water. The exceptions were weak solutions of the ammonium compounds, formic acid 1/6000 G. M., chestnut bark extract, canker extract, and possibly the colloidal solutions of metals.

The typical curve of intake reached its highest point the first 24 hours after injection, then decreased steadily.

Figure 4 shows the rate of intake of an equal number of trees injected July with acids, alkalies, and water. The alkalies surpassed the acids

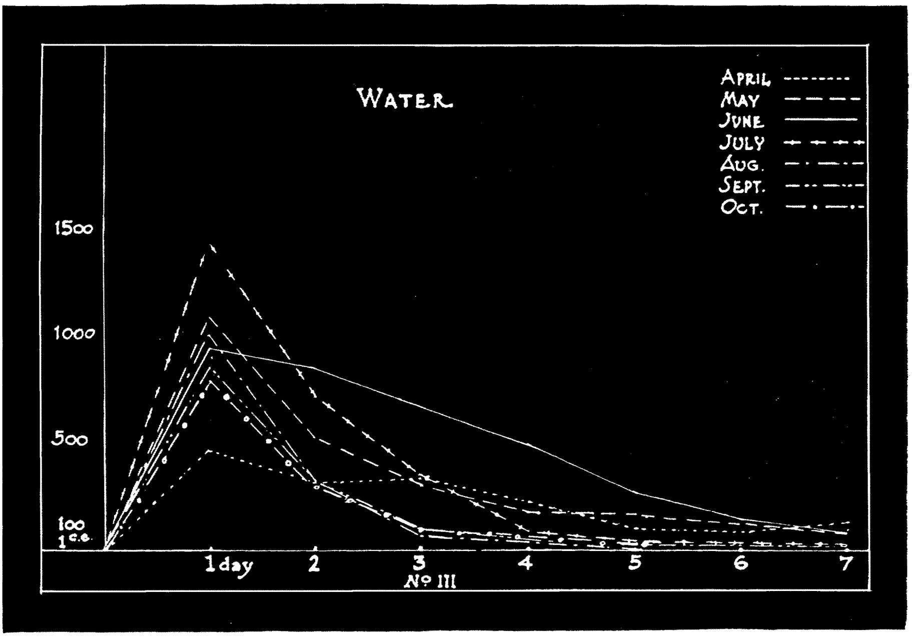

FIG. 3. Graph showing monthly rate of intake of trees injected with water.

in the first 24 hours, but in the second they dropped one half in quantity, and continued to decrease more rapidly than the acids. Because of this rapid decrease in the daily intake of the alkali metals, the trees treated with these compounds usually were injected once a week.

Rankin (28) obtained somewhat similar results when injecting chestnut trees with solutions of lithium nitrate, *i.e.*, the greatest intake was during the first two days and had practically ceased after the fifth and sixth days.

The injections of carbon compounds often ran for three weeks without

a reinjection, sometimes longer. The most marked example of this readiness of intake was a tree injected with para nitro phenol (1/1000 G. M.). This solution flowed into the tree steadily for 41 days without a reinjection. In this time 32½ liters went into the tree through two holes each one centimeter in diameter.

The rate of absorption of the solutions of organic compounds was much

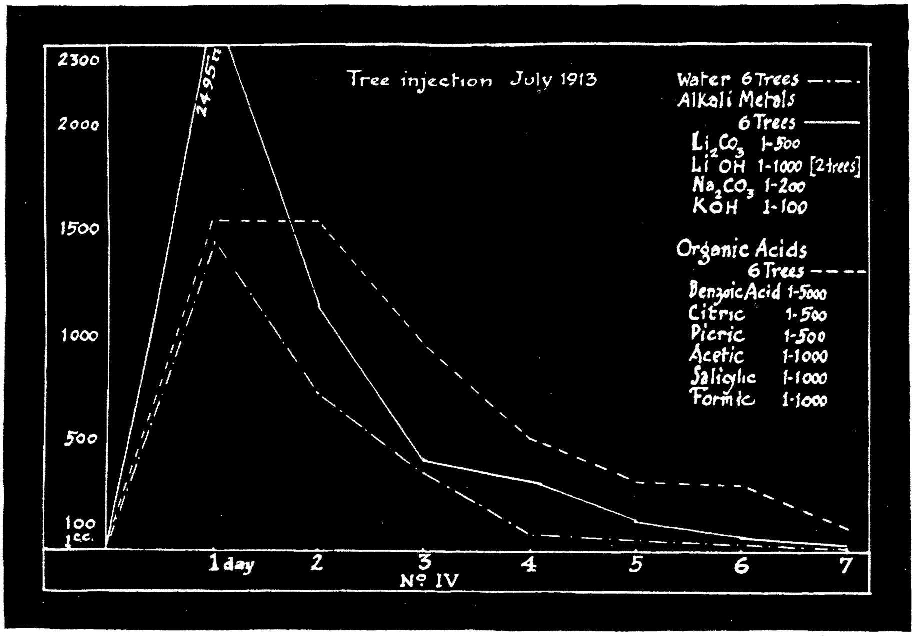

FIG. 4. Graph comparing rate of intake of trees injected during July with water, alkali metals, and organic acids.

greater than the rates of absorption of the solutions of the alkali metals, the heavy metals, and water.

The daily intake of the carbon compounds was extremely irregular. Sometimes the curves seem to indicate that for a short period the intake measured variation in the transpiration of the trees.

The curves of intake of a single tree injected with LiOH 1/200, and those of 3 trees with LiOH 1/500, represented in figures 5 and 6, show how regular was the daily intake of the trees injected with alkali metals. These diagrams also illustrate the fact, common to all the chemicals injected in these experiments, that the greater the concentration of the solutions the greater the intake.

The colloidal solutions of metals were injected into small trees in April before the leaves appeared. All the solutions went in slowly but steadily.

The healthy bark extract went into the trees more readily than the

canker extract. An addition of citric acid to the canker extract increased the intake. These extracts were injected in April and May.

The rate of absorption of solutions of the heavy metals approximated that of solutions of the alkali metals. A solution so concentrated as to be deadly entered the trees more readily than did the more dilute solutions.

During the treatment of the trees a daily record of the weather was kept by means of standard instruments. Some of the weather recording apparatus was not set up until the latter part of April. But after April the

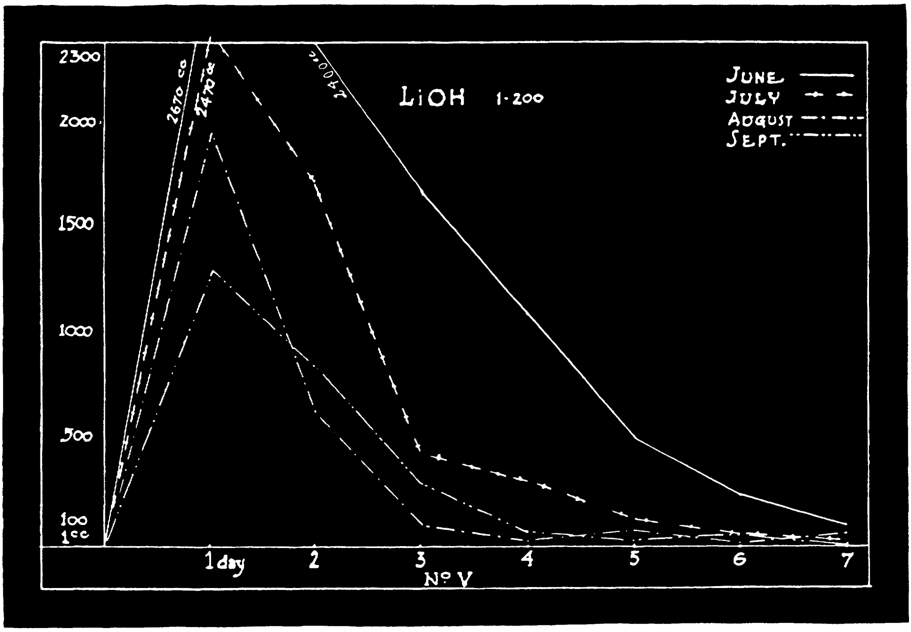

FIG. 5. Graph showing rate of intake of trees injected during the summer months with lithium hydroxide 1/200 G.M.

records were kept until work stopped the last of October. A detailed account of the evaporation and rainfall for this season is given elsewhere (30).

In 1913 the growing season of the chestnut began on April 28, when the leaf buds opened. In May the leaves were nearly mature in size, and flower tassels appeared. By June the leaves were full grown, the flowers had blossomed, and the fruit had set. In July the burs on the trees were half-grown, in August full-grown. In September the nuts began dropping. In October nuts, burs, and leaves dropped from the trees.

Figure 7 shows a monthly compilation of the weather records and of the amount of solution absorbed by a tree per day during each month, every tree injected during the season being used in the computation. The figures in the monthly weather records represented the *mean* of the daily

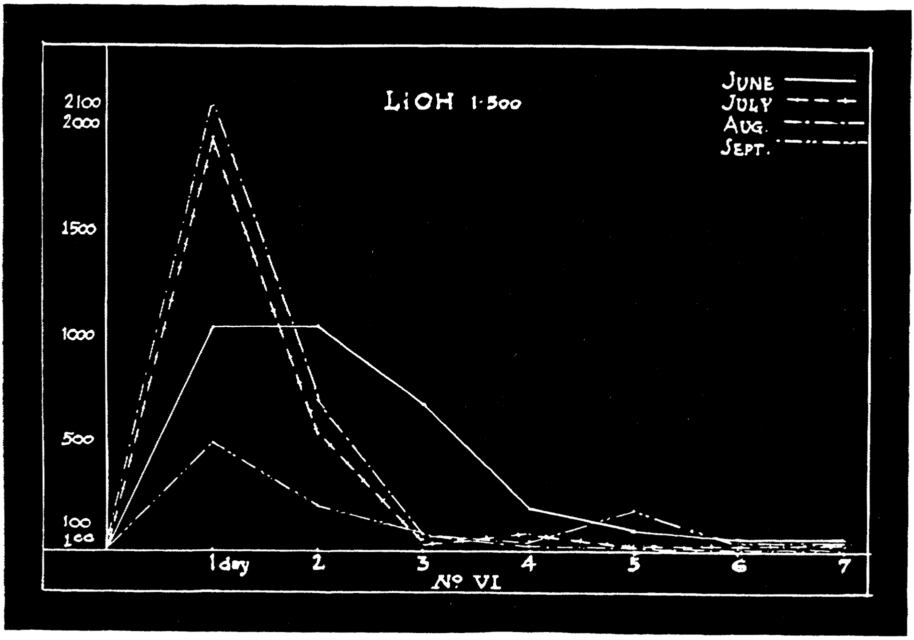

FIG. 6. Graph showing rate of intake of trees injected during the summer months with lithium hydroxide 1/500 G.M.

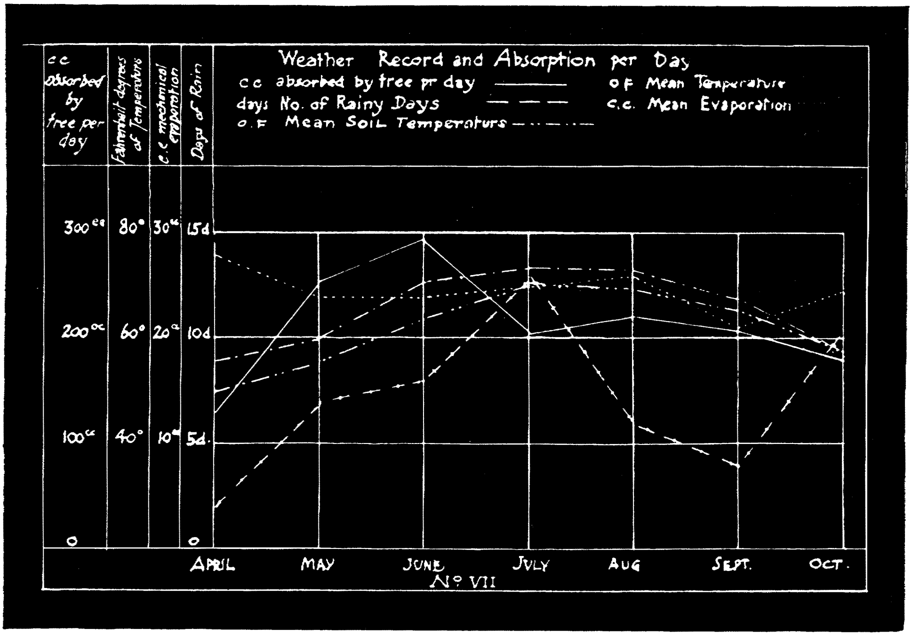

FIG. 7. Graph showing the monthly compilation of the weather records and the amount of solutions absorbed by the trees injected during the year 1913.

records for that month. The amount of rainfall[8] is not recorded in the diagram, because it was noticed that the number of inches of rain which fell on the hill was not so influential in so far as the injections were concerned as was the number of rainy days.[9]

The diagram shows the considerable capacity of the chestnut tree for absorbing chemical solutions.

The *mean* amount absorbed by a tree per day in a 7-day-long injection, was in April 103 cc.; in May 255 cc.; June 299 cc.; July 201 cc.; August 229 cc.; September 224 cc.; and in October 178 cc.

Comparing the records of the intake of the trees with the weather records, it can be seen that the amount of intake is dependent on the stage of development of the trees, which in turn is dependent on the periodic change of weather during the season. The greater the capacity for transpiration, the larger the initial amount of intake. The irregularities of the curves are due to transient changes of weather modified in turn by the changing capacity for transpiration.

From these records of 1913, it appears that the most favorable month for injection of chestnut trees, so far as rate of intake is concerned, was June; after this month came, in rank, July, May, August, September, October, and April.

Summary

A compilation of the records of injections made in 156 Paragon chestnut trees during the growing season of 1913 shows that the trees possessed a considerable capacity for absorbing solutions of substances.

June was the best month for injection in so far as rate of intake was concerned, then came July, May, August, September, October, and April. The rate of intake varied more in April, May, and June than in the summer and autumn months.

Solutions of organic compounds went into the trees more readily than solutions of inorganic compounds, the "true solutions" more readily than the colloidal.

Injected solutions, with a very few exceptions, were absorbed more readily than injected water.

The more concentrated the solutions of chemicals were, the more readily they were absorbed by the trees.

The effects of the injections here described upon the trees and upon *Endothia parasitica* will be discussed in a later paper.

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Washington, D. C.

[8] The rainfall during the period of injection work was 24.7 inches.

[9] For example, in July only 3.1 inches of rain fell, but there were 13 rainy days, the amount of solution absorbed per tree per day dropped during July to 201 cc. In May 4.5 inches of rain fell, with 7 rainy days; the absorption per tree per day was 255 cc. In August 5.8 inches of rain fell with 6 rainy days, and the absorption per tree was 229 cc. per day.

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